AN INVESTIGATION INTO THE RELATIVE RISKS FROM THE ROAD
TRANSPORT OF BLASTING EXPLOSIVES IN MAXIMUM LOADS OF 5 TONNE AND 16 TONNE.

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INTRODUCTION

In 1992 the UK Health and Safety Commission published a report by the Advisory Committee on Dangerous Substances (ACDS) of a five year study into the risks of transporting dangerous commodities in the UK. The risks associated with both road and rail transportation of five such commodities, including explosives, were studied. The risks from these activities were found to be tolerable but at a level requiring consideration for further reduction 'so far as is reasonably practicable'. At the 25th DoD Explosives Safety Seminar, Mr G E Williamson, HM Chief Inspector of Explosives, reported on the ~mdings of that study

Before 1989 UK legislation restricted the quantity of explosives which could be carried in a road vehicle to a maxiinum of 5 tonnes. In 1983 an exemption was granted permitting the carriage of up to 16te of explosives in a freight container, subject to certain specific conditions. In 1989 the Road Traffic (Carriage of Explosives) Regulations sanctioned the carriage of up to 1 6te of HD 1. 1 explosives in 'Special Goods Vehicles'.

This report describes the results of an investigation into the relative risks of transporting blasting explosives on road vehicles in maxiinum size loads of Ste and 16te. The present study makes use of movement data, explosion effects models and many of the assumptions applied in the ACDS study. The report specifically addresses the questions of whether:

(i) an increase in maximum load size might reduce the chance of an explosives accident

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occurring on the public highway by reducing the number of explosives vehicle journeys

undertaken and

(ii) whether any such reduction in accident probability is outweighed by the potentially more severe consequences to be expected from explosions involving larger size loads.

SCOPE OF THE STUDY:

The scope of the study is to assess the relative levels of risk to members of the public from alternative modes for the transport of explosives:

(a) transport in maximum loads of Ste on 2-axle special goods vehicles (SGVs),

(b) transport in maximum loads of 16te on 4-axle SGVs.

The risks included in the scope are those to both people who live close by routes along which explosives vehicles pass and people who travel on such routes. Excluded from the scope are risks to people from the loading and unloading of explosives vehicles. The importance of individual risk (the annual probability that a specified individual will be killed as a result of the materialisation of the hazard) was investigated by the ACDS and was found to be negligible when compared with the importance of societal risk. Individual risk is not, therefore, addressed in this study.

Method of Approach

Estimates for societal risk and expectation values have been obtained using the classical form of quantified risk analysis, which involves applying systematic methods of analysis to each of the following:

Accident identification - in which events are identified which could lead to an initiation of the explosives cargo.

Frequency estimation - in which the frequency of accidental initiation is assessed.

Consequence analysis - in which the consequences of an accidental initiation are assessed.

Risk analysis - in which the results of the f:rst three stages are combined to produce estimates of risk.

The analysis has been undertaken for the transport of a fixed quantity of blasting explosives by the Ste and 16te modes of conveyance. The assumption has been made that carriage of the same quantity of explosives on smaller size vehicles would have required a three-fold increase in the number of journeys undertaken.

ACCIDENT IDENTIFICATION:

An accidental initiation of explosives could, in principle, be caused by a number of different types of energetic stimuli, including:

impact/friction
thermal energy
fragment attack/overpressure
electrostatic discharge
chemical reaction

Various scenarios can be identified under the first of the energetic stimuli listed - impact/friction. These include crash/collision of the vehicle, overhead bridge collapse onto vehicle, aircraft crash onto vehicle, rockfall onto vehicle. Many of these scenarios are intuitively judged to be very low probability of occurrence and are not considered in this study. The accident scenarios studied are:

crashes/collisions of vehicles

fires on explosives vehicles

ignitions of badly packaged, manufactured or off-specification material.

These types of accidents can be regarded as "dangerous occurrences "that would pose a threat to the safety of the explosives cargo but would not necessarily result in an explosion.

FREQUENCY OF INITIATING EVENTS:

Frequency estimate for initiating events were obtained by combining rates for dangerous occurrences with conditional probabilities of initiation and appropriate data for levels of traffic, viz:

$$F = \sum_{i=1}^{I=n} A_i {}^{*}{}^{*} P(I \mid A_i)$$

where	F	is the frequency (annual probability) of an explosives event
	A	is the rate of dangerous occurrence i (per vehicle km)
	L	is the number of vehicle-kms travelled per year
	$P(I \mid A_i)$	is the conditional probability that the cargo would explode give its involvement in accident type i

Historical data have been used to derive rates for dangerous occurrences involving fire and impact. A combination of accident data, trials data and expert judgement has been used to deduce conditional probabilities for the initiation of explosives cargo following a fire or impact accident. Rates for initiations of badly packaged, manufactured or out of specification explosives have simply been derived by noting the historical occurrence of such events: the assumption here is that management standards will remain constant over time.

Crash/collisions of vehicles

The accidents of interest are those severe enough to cause cargo damage. Less severe types of impact accidents are assumed not to pose a threat of initiation and are not considered in this study.

Rates for cargo-damaging collisions were derived from the historical record for such events in the UK. There were six incidents involving commercial explosives vehicles during the 17 year period 1975-1991[(1)]. Movements for this period amount to 7.10^7 km.
Therefore:

severe impact rate = $\underline{9.\ 10^{-8}\ \text{vehicle-km}^{-1}}$

This is an overall rate covering all sizes of explosives vehicles. The question arises as to whether different rates apply to vehicles of different size. The historical accident record is not sufficiently extensive or detailed enough to provide a direct answer to this question. It was necessary, therefore, to consider generic rates for cargo-damaging collisions involving heavy goods vehicles of similar types as those used to move explosives in Ste and 16te loads. An analysis of generic accident data for the two types of vehicle did in fact show that both were equally susceptible to accidents while travelling on trunk roads~[3~]. However, the effect of doubling the accident rate for the larger size vehicle was subsequently examined.

Response of Explosives to Impact

The probability of impact-induced initiation is low as demonstrated by various test criteria and the capacity of items to withstand the impact forces generated in 12m drop trials.

The probability of impact-induced initiation used in this study was derived from a series of drop hammer trials undertaken with cartridges of nitroglycerine-based blasting explosives. These explosives are more sensitive to impact than many types of blasting explosives now commonly used in the UK. The trials were designed to mimic the impact forces which cased explosives cartridges would sustain on falling through a height in excess of 12m onto a hard, unyielding surface. No initiations were observed in a total of 1150 trials[(4)]. A statistical analysis of these results indicates an initiation probability with a value below 2.10^{-3} (90% confidence level). None of the six transport accidents referred to in the previous section resulted in explosives cartridges sustaining a greater level of damage than that produced in the drop hammer trials.

Accordingly, the probability derived from these trials, 2.10^{-3}, was used in this study. The value may be combined with the cargo-damaging collision rate derived in the previous section to produce an impact-induced initiation rate of 2.10^{-10} vehicle-km^{-1}.

Fires on Road Vehicles

Cargo-damaging fire rates have been derived from a fault tree analysis of the various sources of ignition of vehicle fires and the circumstances under which these fires could spread to cargo. The fault trees were quantified using generic truck fire data, suitably factored down by expert judgement and data where available to take account of statutory fire precaution measures required for explosives-carrying vehicles.

Four broad categories of ignition sources were identified and the following rates of ignition derived:-

(a) Fires ignited by electrical or mechanical faults in the cab or engine compartments of vehicles: $3.\ 10^{-10}$ vehicle-km^{-1}.

(b) Tyre fires, ignited by binding brakes, faulty bearings, deflated tires etc: 2.10^{-9} vehicle-$km^{-1.}$

(c) Fires ignited maliciously or by the use of smokers' materials: 2.10^{-11} vehicle-$km^{-1.}$

(d) Fires ignited in crashes or collisions: 1.10^{-10} vehicle-$km^{-1.}$

Total: $2.42.10^{-9}$ vehicle-km^{-1}, rounded to 2.10^{-9} vehicle-km^{-1}.

Response of Explosives to Fire

Different types of explosives can be expected to show different types of reaction on being exposed to heat and flame. Nitroglycerine-based explosives are most likely to burn to explosion, whereas slurry and emulsion explosives are unlikely to burn to explosion by themselves. However, these latter types of explosives could be sympathetically detonated by an initiation of any more sensitive types of explosives that may be present in the load. An analysis of movement data carried out for the ACDS study indicated that about 26% of vehicles carrying commercial explosives convey loads containing only insensitive types of substances (this ratio is essentially constant across the range of load sizes). The ACDS conservatively judged the burn-to-explosion probability for these types of substances to be no greater than 10%. For other types of loads the ACDS chose a burn-to-explosion probability of unity.

	Fire Rate (per vehicle-km)		Initiation Probability		Initiation Rate (per vehicle-km)
Sensitive	2.10^{-9}	*	1	=	2.10^{-9}
Insensitive	2.10^{-9}	*	0.1	=	2.10^{-10}

Initiation of BadIv Packaged Manufactured or Off-specification Explosives

A rate for the occurrence of this type of event can be crudely estimated by noting the one incident that has occurred on a road vehicle during the last 40 years and dividing this by a rough estimate for the explosives vehicle kilometerage accrued during the period. The value obtained is:6.10^{-9} vehicle-km^{-1}. However, with only one incident and an uncertain number of movements this rate is not very robust.

The rate used in the "base case" analysis presented in this study is that derived by the ACDS, who considered the past incidence of such accidents on both road and rail vehicles. The rate derived by the ACDS was based on three incidents during a 40 year period (the most recent such accident occurred in 1989):

Upper bound value	=	6.10^{-9} vehicle-km^{-1}
Mean value		1.10^{-9} vehicle-km^{-1}
Lower bound value	=	2.10^{-10} vehicle-km^{-1}

It is seen that the rate is subject to a certain amount of statistical uncertainty.

Sensitivitv tests

The values derived in the frequency analysis were subject to uncertainty. Uncertainty may be treated in various ways in risk analysis; the approach adopted in this study was to carry out a "base case" analysis and several sensitivity tests in the spirit of the "cautious best estimate" approach to risk analysis advocated in the UK HSE document 'Risk Criteria for Land-use Planning in the Vicinity of Major Industrial Hazards'(5) This means that every attempt was made to use realistic, best-estimate assumptions in the base case analysis; but where there was difficulty in justifying an assumption some pessimistic estimate was chosen, and the sensitivity of the overall results to that assumption tested. The rates for initiating events used in the present study were as follows:

Impact-induced Initiation

	Rate for Ste vehicle	Rate for 16te vehicle
Base case	2.10^{-10} vehicle-km^{-1}	2.10^{-10} vehicle-km^{-1}
Sensitivity Test 1	2.10^{-10} vehicle-km^{-1}	4.10^{-10} vehicle-km^{-1}

Sensitivity Test 1 assumes 16te trucks are twice as likely to be involved in cargo-damaging crash/collision incidents as Ste trucks.

Fire-induced Initiation

	Rate for Ste vehicle	Rate for 16te vehicle
Base case	2.10^{-10} vehicle-km^{-1}	2.10^{-10} vehicle-km^{-1}
Sensitivity Test 2	2.10^{-10} vehicle-km-1	32.10^{-9} vehicle-km^{-1}

Sensitivity Test 2 assumes tyre fires - the dominant cause of truck fires in the UK - are twice as likely to occur on 16te 4-axle trucks as on 5te 2-axle trucks.

Initiation of Unsafe Material

	Rate for Ste vehicle	Rate for 16te vehicle
Base case	1.10^{-9} vehicle-km-1	1.10^{-9} vehicle-km^{-1}
Sensitivity Test 3	1.10^{-9} vehicle-km^{-1}	3.10^{-9} vehicle-km^{-1}
Sensitivity Test 4	-	-

Sensitivity Test 3 assumes the same overall frequencv of initiation of unsafe items for the Ste and 16te modes of transport (three times as many journeys are required by the Ste mode as be the 16te mode).

Sensitivity Test 4 assumes that unsafe items can be ignored - this is in consideration of new regulations that came into force in the UK in 1992, requiring testing and packaging of explosives to defined standards.

CONSEQUENCE ANALYSIS

An initiation of blasting explosives on a road vehicle could cause damage and harm from blast, fragment, thermal and ground shock effects. The most damaging of these effects is likely to be blast, particularly as blasting explosives are transported in soft packaging material which cannot form high energy primary fragments. Accordingly, the fatality assessment model used in this study is based primarily on blast effects.

Fatal primary and tertiary blast injuries usually only arise with relatively high levels of overpressure (in excess of ~ 30 psig) and thus generally only occur amongst people in very close proximity to an explosion. However, structural collapse, leading to fatal secondary blast injuries, can occur at much lower levels of overpressure (2-3 psig), and it follows that structural collapse is likely to be the dominant mechanism of harm from explosions in built up areas. It also follows that blast effects are likely to cause greater number of fatalities among people indoors than among people in the open.

Although blast is expected to be the dominant mode of harm, the effects of fragments cannot be entirely dismissed. High energy secondary fragments would be produced from the structural material of the vehicle if this were to disintegrate in an explosion. In fact, the fireman killed in the 1989 Peterborough explosion died as a result of being struck by such a fragment(6). People in the open are likely to be at greater risk from fragments than people located inside buildings, the latter being afforded some degree of protection by structural features such as walls and roofs.

It follows from all this that a comprehensive fatality model for blasting explosives would be based on an analysis of the effects on people of both blast and fragments and would differentiate between people indoors and outdoors. The model would also need to take account of two important factors:

(a) An accidental initiation of explosives on a vehicle may or may not come about without much warning. Therefore, models based on fatality data obtained from wartime bombing incidents - when most people would have been in air-raid shelters - would be inappropriate for use in the present study.

(b) In an urban environment people would be afforded a degree of protection against fragments by the walls of buildings and other structural features, so that formulae relating to open sites around storage facilities would also be irrelevant to this study.

Fatality Model

A comprehensive model such as that described was not available at the time the present study was undertaken. A simplified approach was adopted that, nonetheless, took account of issues (a) and (b) above by deriving fatality estimates from a model based on an analysis of casualty data from 12 wartime V2 rocket attacks(1). These missiles hit the ground travelling at a velocity of around Mach 3 and thus struck without warning. The model allowed estimates to be made for the overall percentage of fatalities to be expected among groups of people (including those indoors and out) located at various distances from an explosion of specified size.

Hazard Ranges and Population Densities

The model was used to estimate ranges to 90%, 50% and 10% fatalities (denoted L90, L50 and L10 respectively) for loads of Ste and 16te. These hazard ranges were used in conjunction with data for on-road and off-road population density to derive estimates for the numbers of people likely to be killed by accidental initiations of Ste and 16te explosives loads. The procedure involved the determination of:

(a) the numbers of people both on-road and off-road encompassed by the various hazard ranges and

(b) the average fatality probability for people within a specified range.

The numbers of people encompassed by the hazard ranges will be dependent on three factors:-

(a) The extent of any clear zone between the road and the off-road population.

(b) The density of the off-road population.

(c) The density of the traffic on the road.

An important point to be borne in mind when considering the first of these factors is that a significant separation is likely to be found between the traffic and roadside population bordering trunk roads, while population bordering a single carriageway is, by comparison, likely to be much closer to traffic.

Hazard Zones

Figure 1 illustrates the various hazard zones surrounding an explosives lorry at a point on a trunk road. Zone 1 is that area of the nearside off-road population encompassed by the L90 hazard range; Zones 2 and 3 are those areas of the nearside off-road population which lie between the L90-L50 and L50-L10 hazard ranges respectively; Zone 4 is that area of far-side off-road population encompassed by the L50 hazard range, while Zone 5 is that area of the far-side off-road population that lies between the L50-L10 hazard ranges - it will be seen that the L90 hazard range does not extend beyond the off-side carriageway; Zone 6 is the area of nearside carriageway immediately behind the explosives lorry that is encompassed by the L90 hazard range; Zones 7 and 8 are the areas of backed-up traffic bordered by the L90-L50 and L50-L10 hazard ranges respectively; Zone 9 is that area of the off-side carriageway encompassed by the L90 hazard range; and finally Zones 10 and 11 are those areas of the off-side carriageway bordered by the L90-L50 and L50-L10 hazard ranges respectively. The sum of the products of area and population density for each hazard zone gives the number of people at risk from a potential explosives event. It will be seen that the L10 hazard range is used as a "cut off" in determining numbers of people at risk. In practice fatalities may occur beyond this range but these will account for only a very small proportion of total fatalities; the use of the L10 hazard range as a "cut off" does not, therefore, lead to any significant under estimation of risk.

Analyses of hazard zones are required for all points along a route. These analyses must take account of the various categories of off-road population - urban, suburban, built-up rural and rural - to allow estimates to be derived for the numbers of people, both on-road and off-road, that are encompassed within the hazard range of the truck as it travels along the route. These analyses can be performed very quickly with the aid of a geographical information system. An example of this type of analysis for a 16te truck at a point along a section of trunk road is shown in Table 1.

Table 1: Fatality Estimates for Trunk road with Urban Population Nearside and Suburban Population Off-side - 15te load.

Zone (See Figure 2)	Zone Area (m^2)	Population Density (m^{-2})	Average Fatality Probability	Expected Number of Fatalities
1	201	4.21E-3	0.95	0.8
2	2759	4.21E-3	0.7	8.1
3	1884	4.21E-3	0.3	2.4
4	1527	1.31E-3	0.7	1.4
5	1500	1.31E-3	0.3	0.6
6	207	5.0E-2	0.95	9.8
7	314	5.0E-2	0.7	11.0
8	121	5.0E-2	0.3	1.8
9	385	2.5E-2	0.95	9.1
10	623	2.5E-2	0.7	10.9
11	246	2.5E-2	0.3	1.8
				Total 58

The total given in Table 1 can be split between on-road and off-road fatalities. The total on-road fatalities are obtained by summating estimates for Zones 6, 7, 8, 9 10 and 11, while the off-road fatalities are obtained by summating estimates for Zones 1, 2, 3, 4 and 5 (see Figure 1). The numbers of on-road and off-road fatalities are 45 and 13 respectively. Similar analyses have been carried out for other sections of the route.

RISK ANALYSIS

The next step was to obtain estimates for the frequency with which explosives events could potentially occur along the various sections of route. These estimates were obtained from the product of three variables:

(a) rate of occurrence (vehicle-km-^{1}) of initiating events,

(b) annual kilometerage travelled by explosives vehicles

(carriage of explosives on Ste vehicles requires three times the numbers of journeys as carriage of explosives on 16te vehicles),

(c) ratio of the length of route section to the total length of route.

The numbers of fatalities to be expected from such events were estimated by the procedure described in the previous section. The frequency/fatality data so obtained were then processed to produce frequency estimates for events resulting in specified numbers of fatalities. In the present study, the data were processed to provide frequency estimates for events resulting in numbers of fatalities falling within the following bands: = 1, > =3, > = 10, > = 20, > =30, > = 40, > = 50, > = 60. The results for the "base case" analysis for the 16te and Ste modes of transport are shown in Tables 2 and 3 respectively.

Table 2:F/N Data for Transport of Explosives by 16te Mode of Conveyance - Base Case.

N	FREQUENCY OF N OR MORE FATALITIES (10^6 yr^{-1}) OFF-ROAD	ON-ROAD	TOTAL
1	1085	334	1085
3	1085	80	1085
10	1085	18	1085
20	1085	0	1085
30	379	0	387
40	379	0	386
50	273	0	294
60	0	0	0

Table 3: F/N Data for Transport of Explosives by Ste Mode of Conveyance - Base Case

N	FREQUENCY OF N OR MORE FATALITIES (10-6 yr^1) OFF-ROAD	ON-ROAD	TOTAL
1	3254	493	3254
3	3254	57	3254
10	3254	0	3254
20	1136	0	1162
30	818	0	960
40	0	0	0
50	0	0	0
60	0	0	0

Plots of the above data are shown in "faired" form in Figure 2. The faired curves have been obtained by plotting the geometric means of the adjacent Fs and Ns in the 'Offroad', 'On-road' and 'Total' columns in the above tables. The "fairing" procedure allows F/N curves to be drawn rather than step-wise F/N graphs.

It is seen that fatal accidents occur more often with the Ste mode of transport but that potential numbers of casualties are greater with the 16te mode. This result, of course, could have been predicted simply from a consideration of the smaller load sizes and greater mileage associated with the Ste mode. The question which needs to be resolved is which of the two modes is the more likely to cause the greatest numbers of fatalities over time. This question can be resolved by processing the f/n data to determine annual expectation values for numbers of fatalities caused by the two alternative modes of transport. Expectation values (E) are derived from the following formula:

$$E = \sum_{i=1}^{28} fi * ni$$

where fj is the frequency of occurrence of an explosives event in Section i of the route and n is the number of fatalities expected from the occurrence of the event. In this particular case the route is composed of 28 separate sections, thus there are 28 summations in the above formula.

The expectation values derived in the base case analyses are:

Ste mode of transport	0.074
16te mode of transport	0.037

Thus it is seen that in the long run the Ste mode of transport is estimated to cause twice the number of fatalities as the 16te mode of transport.

The curves drawn in Figure 2 show that the risks to road users are dominant over those to the roadside population. This result is obtained in all of the further sensitivity tests. However, it should be appreciated that the consequence model used in this study was not specifically designed to predict casualty figures for people located inside vehicles - though it will provide some measure of relative levels of fatalities to be expected from explosions of different size - and thus the absolute values for the numbers of derived fatalities should be treated with caution and not taken outside the scope of the present study.

RISK TOLERABILITY

The tolerability of the risks may be judged by comparing them with numerical criteria proposed in the recently published ACDS report[1]. The comparison is made in Figure 3. This shows the base case F/N curves for the Ste and 16te modes of transport together with lines denoting boundaries of negligible risk (Line A) and local maximum tolerable risk (Line B). On the basis of these criteria, risks above Line B would be regarded as intolerable <u>if thev were concentrated in one localitv</u>, while risks below Line A would be regarded as negligible, and risks between Lines A and B, again, <u>if concentrated in one locality</u>, would need to be reduced to as low a level as reasonably practicable (ALARP). It will be seen from Figure 10 that the risks from both the Ste and 16te modes of transport fall below Line B; thus they would not be regarded as intolerable even if they were concentrated in one place. Of course, the risks are not concentrated in one locality, and in this respect they can be said to pass a very strict test of tolerability.

CONCLUSIONS

The national risk from the road transport of explosives has been assessed by the ACDS and found to be tolerable but not negligible: the risk is of a level which requires reduction to a level which is ALARP. The study described in the present report builds on work undertaken by the ACDS: it assesses the relative risks from the transport of blasting explosives on road vehicles in maximum load sizes of Ste and 16te, the latter being permitted under regulations introduced in 1989[(2)].

The objective of the study has been to assess whether a decrease in the number of explosives movements brought about by an increase in maximum load size might reduce the chance of an explosives event occurring on the public highway and whether any such reduction is outweighed by the more severe consequences that would result from initiations of larger size loads.

The relative risks of the Ste and 16te modes of transport have been assessed by comparing F/N curves and estimates of expectation values for annual numbers of fatalities. The sensitivity of the results to certain key assumptions made in the analysis has been explored in sensitivity tests.

The balance of evidence suggests that movements of explosives in large size loads would, in the long run, cause fewer fatalities than more numerous movements of explosives in smaller size loads. The base case analysis presented in this report suggests that over time the 16te mode of transport might be expected to cause about half the number of fatalities as the Ste mode of transport. The results of the base case analysis are regarded as a "cautious best estimate " of the risks, but these estimates are subject to uncertainty. However, sensitivity tests show that even if the rates of impact- and fire-induced initiation for 16te vehicles were twice those for Ste vehicles, the greater number of fatalities would still occur with the Ste mode of transport.

The sensitivity tests show that the risk estimates <u>are</u> sensitive to assumptions made about the significance of badly manufactured, packaged and off-specification explosives as potential causes of accidental initiation. If it is considered that unsafe material is the dominant cause of accidental initiation, and that the same <u>frequencv</u> of initiation of unsafe material applies to both modes of transport (ie <u>rate</u> of initiation for 16te vehicles is three times that for Ste vehicles), then the 16te mode of transport would cause the greater number of fatalities in the long run. However, it is noted that new regulations which came into force on 1 March 1992 require testing and packaging of explosives to defined standards; adherence to these regulations should decrease the chance of initiation due to unsafe material. Further sensitivity tests show that if the risks of unsafe material are discounted, or are shown to be insignificant by comparison with the risks from other causes of accidental initiation, then the Ste mode of transport would be expected to cause the greater number of fatalities over time.

Thus it is concluded that the balance of evidence suggests that the 16te mode of transport is safer than the Ste mode of transport, in the sense that the former might be expected to cause fewer fatalities over time.

USEFULNESS OF QRA TO IMPROVE SAFETY

The credible accident scenarios identified here and in the previous ACDS study include crashes/collisions, fires, and ignitions of badly packaged, manufactured or off-specification material. To protect against these a number of areas for further study/attention have been identified:

methods of reducing occurrences of vehicle (notably tire) fires.

the effectiveness of cargo fire protection.

- a fire screen or gap to prevent risk of fire between engine compartment and cargo compartment constructed to give protection against fire attack for a minimum of 15 minutes;

or

- load compartment constructed to give protection against fire attack for a minimum of 15 minutes;

and

arrangements for preventing the spread of fire within compartment;

the reasonable practicability of replacing wooden dunnage etc. with non-flammable material, ie use of cargo nets, webbing and restraining bars;

the need for improved packaging standards for sensitive explosives items;

arrangements to prevent interaction of mixed loads;

vehicles carrying mixed loads of 1. 1B detonators with HE must be specially constructed to provide proven effective segregation. All countries operating under ADR prohibit the carriage of detonators with explosives regardless of vehicle design.

Special Goods Vehicles are already required to have suitable dust tight and flameproof electrics, together with cut off switches for fuel and power systems.

REFERENCES

1. Health and Safety Commission, 'Major Hazard Aspects of the Transport of Dangerous Substances: Report and Appendices', a report by a sub-committee of the Health and Safety Commission's Advisory Committee on Dangerous Substances, HMSO, 1991.

2. Health and Safety Commission, 'Carriage of Explosives By Road, Road Traffic (Carriage of Explosives) Regulations 1989, Approved Code of Practice with Regulations and Guidance', HMSO, 1989.

3. Moreton, P A, 'An Investigation of the Relative Risks from the Road Transport of Blasting Explosives in Maximum Size Loads of Ste and 16te, HMSO, London, 1993, ISBN 0-853563861.

4. Pittam,D.A., 'An Assessment of the Hazards Associated with the Handling, Loading and Transport of Packed Explosives', Nobel's Explosives Company Ltd., 1981 .HSE,

5. 'Risk Criteria for Land Use Planning in the Vicinity of Major Industrial Hazards: A Discussion Document', HMSO, 1989.

6. HSE, 'The Peterborough Explosion', HMSO, 1989.

Figure 1 : Hazard Zones Around Explosives Vehicle Travelling on Trunk Road

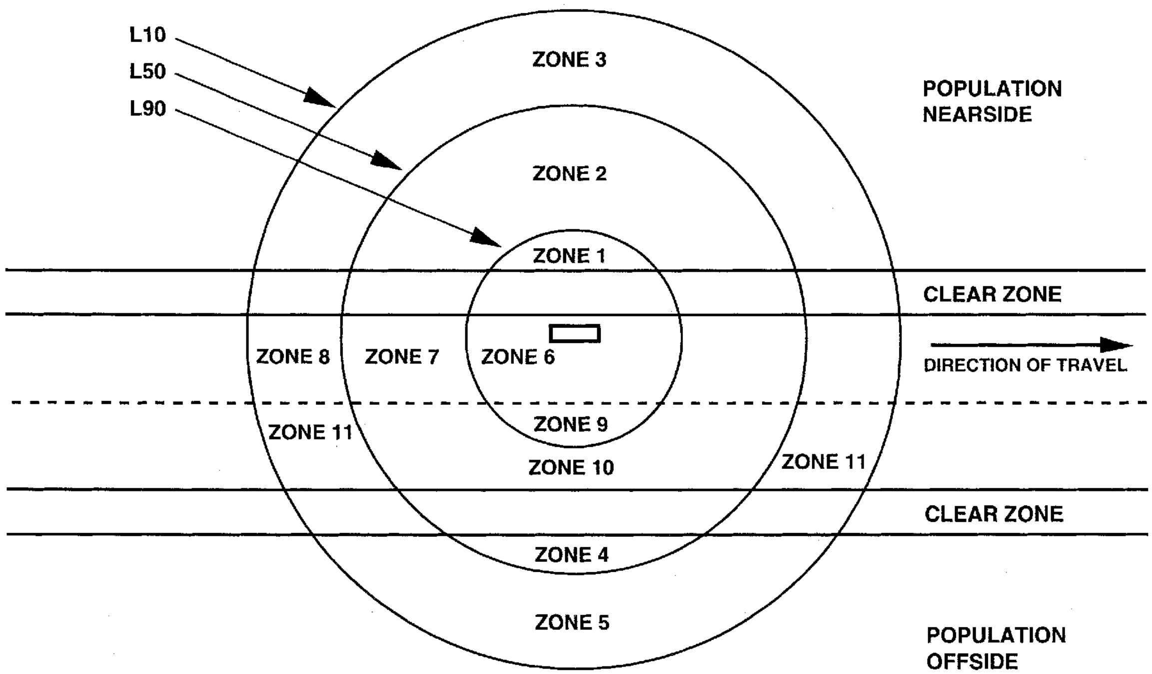

Figure 1 : Hazard Zones Around Explosives Vehicle Traveling on Truck Road

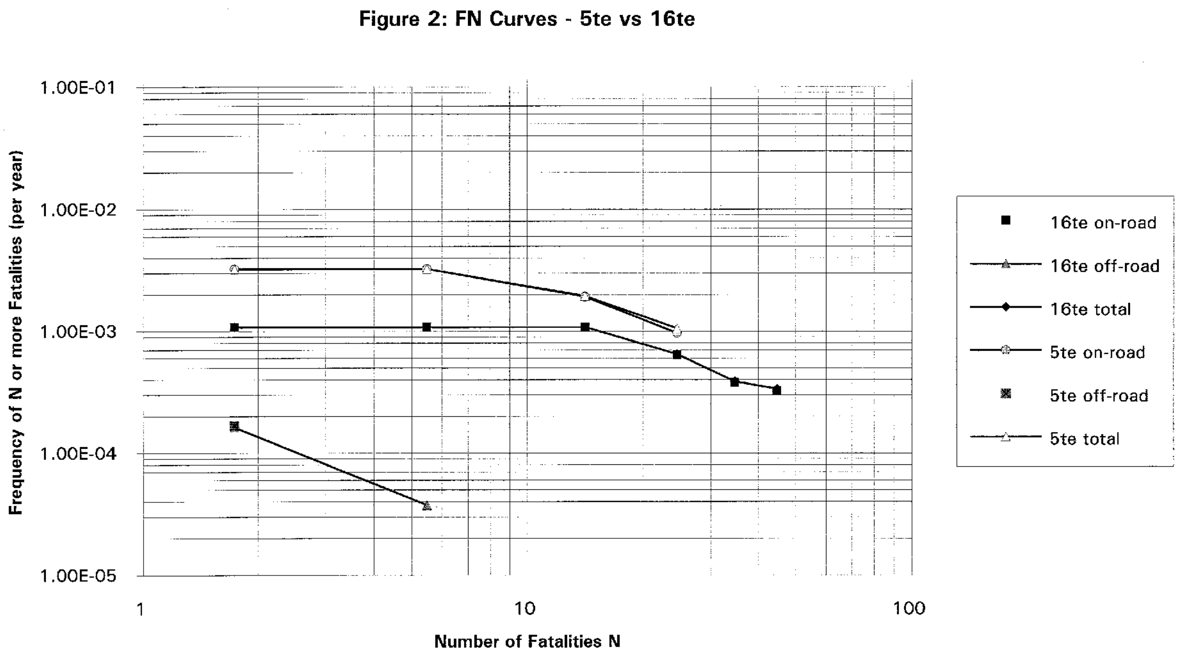

Figure 2 : FN Curves - 5te vs 16te

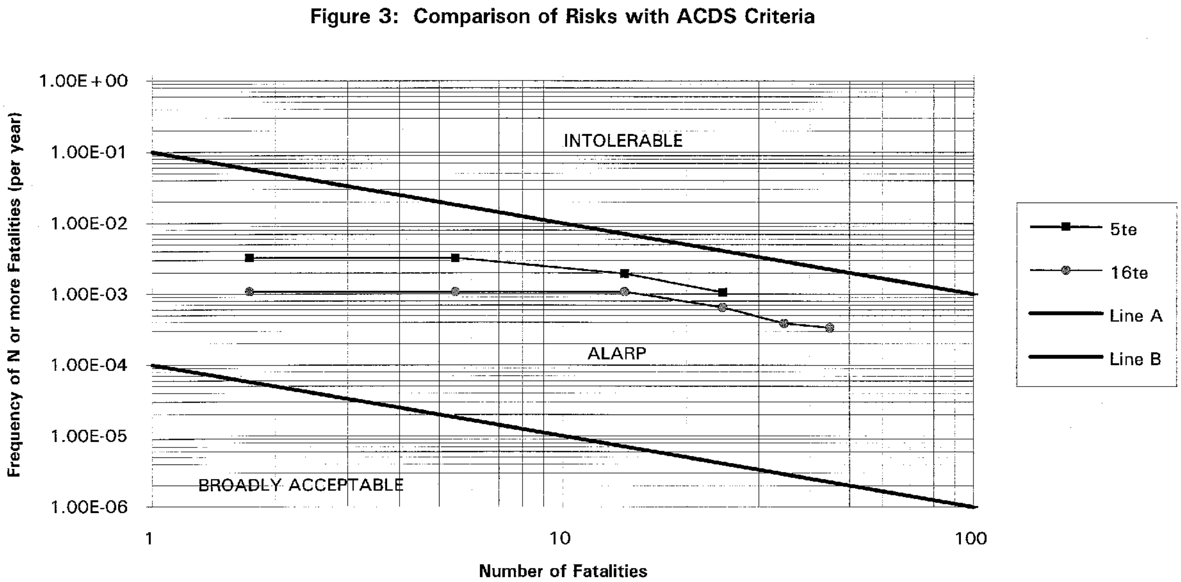

Figure 3 : Comparison of Risks with ACDS Criteria